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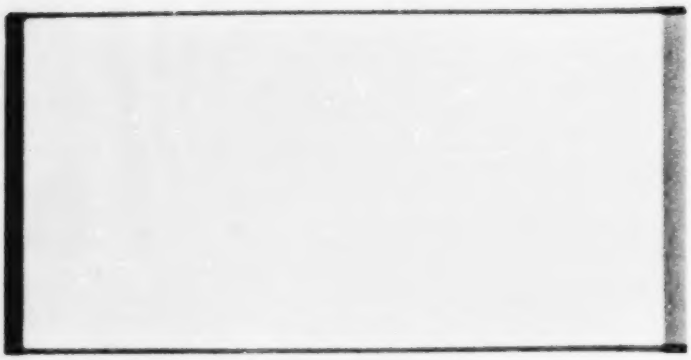

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BOTTOM ASH: A POTENTIAL AGGREGATE FOR HIGHWAY BASE AND SUBBASE COURSES

Report No 83-222-K

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ABSTRACT

This report summarizes the physical and chemical properties of various types of bottom ash obtained from a literature survey and from tests on samples of Ontario Hydro bottom ash. Different applications of bottom ash in highway pavement construction, particularly in the utilization as a subbase course, are discussed. On the basis of the collected information, it is concluded that bottom ash is a potential aggregate for highway base courses.

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To Mr. D. Erwin
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Attn: Mr. J.H.P. Buckingham

BOTTOM ASH: A POTENTIAL AGGREGATE FOR HIGHWAY BASE COURSES

1.0 INTRODUCTION

A request has been made by Mr. J.H.P. Buckingham of the Supply Procurement Division to obtain information pertaining to the suitability and feasibility of using Ontario Hydro bottom ash as a qualified pavement base or subbase course. At the present time, there are limited test data available to support the utilization of Ontario Hydro bottom ash as a highway subbase. Consequently, it has been difficult in some cases for contractors to obtain the necessary approval from provincial and municipal highway agencies to use bottom ash as a substitute for conventional natural aggregate materials in highway construction. In this study, the properties of various bottom ash materials were collected from the literature and also from tests performed in the Soils Laboratory of the Civil Research Department. This information will be useful to users of bottom ash for various applications. With this background information, a number of literature case records dealing with the use of bottom ash for the construction of highway base courses are presented and discussed.

From this study, a better understanding of the properties and performance of bottom ash was obtained and the potential use of bottom ash as a highway base course can be furthered.

2.0 PROPERTIES OF BOTTOM ASH

Bottom ash is typically greyish black in colour, subangular in shape and generally has a glassy texture. Some particles have a somewhat porous structure.

In the following subsections, some pertinent properties of bottom ash are summarized. The data were obtained either from a literature search or from tests carried out in the Soils Laboratory of the Civil Research Department.

2.1 Particle Size Distribution

The particle size distribution curves of three different bottom ash samples from Lakeview, Lambton and Nanticoke TGS are illustrated in Figures 1 to 3. For comparative purposes, Figures 4 and 5 show grain size curves for a number of bottom ash samples from several generating stations in the United States. The test data indicate that the particle size distribution of bottom ash generally falls within the Ontario Ministry of Transportation and Communications (MTC) gradation limits for granular "B" Type I aggregate material/2/.

2.2 Relative Density (Specific Gravity)

Table I shows the relative density (specific gravity) values of various bottom ash samples. These variations are considered to be due to changes in the chemical constituents of the ash resulting from the different coals from which they are produced.

2.3 Density

The density of a compacted bottom ash specimen depends on the compactive effort, the water content of the mix and the ash material itself. Figure 6 and Table II contain results from various sources. The data indicate that the bottom ash is a lightweight material because the density of the compacted ash is generally about 80% of that of a compacted natural aggregate.

2.4 Hydraulic Conductivity (k)

Generally, the value of hydraulic conductivity (k) of most compacted bottom ash is equivalent to that of sandy materials, which have good drainage characteristics. Table III summarizes k test results on Lakeview TGS bottom ash samples and Table IV identifies comparable results from the literature search.

It appears that the k value of Lakeview bottom ash is lower than that of US bottom ash. This is attributed to physical differences in the materials and the variations in compacted densities.

2.5 Angle of Internal Friction (Ø)

Values of Ø from the literature search are summarized in Table V. These results were obtained from direct shear tests.

Limited test data obtained by Ontario Hydro's Soils Section/9/ were in general agreement with the literature results. The high frictional angle values may be attributed to the angularity and rough surface characteristics of the bottom ash particles.

2.6 One-Dimensional Compression

Figure 7 shows one-dimensional compression curves for two samples of US bottom ash, one in a relatively loose state and the other in a relatively dense state. For low stress levels, this indicates that the compressibility of bottom ash is comparable to that of sand placed at a similar density.

2.7 Breakdown of Ash Particles

To obtain information on the possible breakdown of bottom ash particles during standard Proctor compaction effort, sieve analyses were performed on two Lakeview bottom ash samples before and after compaction tests. Figure 8 shows the test results, which indicate only minimal breakdown of the ash particles.

2.8 Water Absorption, Sulphate Soundness and Los Angeles Abrasion

Test data on bottom ash samples pertaining to water absorption, sulphate soundness and Los Angeles abrasion are presented in Tables VI and VII. These data were obtained by US researchers/3,4/.

The sodium sulphate soundness and the Los Angeles Abrasion test values for Lakeview bottom ash are 3% and 45% respectively/5/. As a general rule, aggregates with a percentage loss in the Los Angeles abrasion machine equal to or less than 40% are satisfactory.

2.9 California Bearing Ratio (CBR)

Several California Bearing Ratio (CBR) tests were performed on a number of Lakeview bottom ash samples both in the "unsoaked" and "soaked" conditions. The tests results are presented in Table VIII.

2.10 Chemical Properties

Table IX contains typical analyses of Lakeview bottom ash/5/, which is composed mainly of silicon, alumina and iron. Table X shows the leachate characteristics of Lakeview bottom ash as obtained by the "24-hour shake test". The ash leachate is slightly alkaline and has low concentrations of the major ions. Data from a column experiment/10/ also indicated very low

concentrations of sulphate (<35 mg/L) in the leachate samples collected from a loosely compacted Lakeview bottom ash. This low level of sulphate concentration should not pose any concern to concrete materials.

3.0 UTILIZATION OF BOTTOM ASH

Bottom ash has been used in different engineering applications and many examples have been reported. In this report, only the uses of bottom ash for highway base courses will be discussed.

3.1 Bottom Ash as a Non-Stabilized Highway Base Course

(1) One of the first attempts in the USA to utilize non-stabilized bottom ash in a base course was in the 1971 construction of the access road to the Law School and Computer Centre complex on West Virginia University's Evansdale Campus. It was found that the bottom ash produced by the Fort Martin Station of the Allegheny Power System would pass the specified gradation, abrasion and sulphate soundness requirements of the West Virginia Department of Highways for a Class 2 base course, as shown in Table XI. The bottom ash was compacted with a 10-ton tandem steelwheel roller. The bottom ash could be spread and compacted well when placed at its optimum moisture content, or slightly above, as determined by the standard Proctor compaction procedure. However, the bottom ash lost stability when it dried out, and it was necessary to keep the material wet in order that paving and other construction equipment could be operated satisfactorily on its surface.

To find a solution to the stability loss problem after drying, a laboratory study was conducted at West Virginia University using bottom ash and fly ash. It was concluded that the addition of 30% fines in the form of fly ash provided the required binder and that good initial density and dry stability could be achieved.

(2) As part of the relocation of West Virginia Route 2 in the Ohio Valley south of Wheeling, untreated bottom ash was used as a base course for shoulders and lightly travelled access roads. The bottom ash was placed at an average moisture content of 14% and compacted to densities in excess of 95% of the standard Proctor value. This material also met the West Virginia Highway Department's gradation and quality requirements.

(3) On another West Virginia Route 2 base course application where a mixture of bottom ash and blast furnace slag was used, high densities and excellent dry stability were achieved. Bottom ash was blended with blast furnace slag, meeting ASTM No 467 grading, to satisfy the gradation requirements of the West Virginia Department of Highways for Class 1 crushed aggregate base course. Table XII is a comparison between the requirements for Class 1 crushed aggregate base course and the properties of a typical ash-slag mixture. The mixture was placed and compacted to a total thickness of 23 cm with compaction water content ranging from 6 to 8%. The compacted dry density generally exceeded the specified value of 95% of the laboratory maximum dry density of 1682 kg/m^3. This case record indicated that untreated bottom ash could be used satisfactorily as a base course when the proper gradation and combination of materials were used.

(4) A mixture of bottom ash and fly ash was used as the base course for the reconstruction of the access roads to the Fort Martin station of the Allegheny Power System. The roads did not carry a large volume of traffic, but many of the vehicles using these roads were heavily loaded.

A 60-40 bottom ash-fly ash combination was used which proved to be a satisfactory blend for the working conditions encountered. Compaction was first attempted with a three-wheel roller which proved to be unsatisfactory. Loss of stability beneath the roller on slight grades made the use of this roller impractical, and it was replaced with a vibratory roller having rubber-tired rear driving wheels and a steel wheel front roller (Rayco Model 400RT-1). This roller achieved good compaction performance on both the bottom ash alone and the bottom ash-fly ash mixture. Visual observation and the specification of minimum roller coverages were used for compaction control. Generally, 6 to 10 passes of the vibratory roller were sufficient to produce a stable, well-compacted bottom ash layer.

Dry densities of approximately 1611 kg/m^3 and 1659 kg/m^3 were achieved for 10 and 20 roller passes respectively. The average field moisture content was 18.1%, which was considerably greater than the standard Proctor optimum moisture content of 10%. However, the dry densities achieved in the field ranged from 96.0 to 105.7% of the standard Proctor maximum density of 1562 kg/m^3.

3.2 Bottom Ash Used as a Stabilized Highway Base Course

Bottom ash has also been used successfully as a stabilized base course as reported by Moulton/3/. The first known large-scale application of a Portland cement-stabilized bottom ash base course in the US was in the 1971-72 relocation and reconstruction of West Virginia Route 2 south of Wheeling. Blending of several supplies of bottom ashes was necessary to meet the West Virginia Department of Highways gradation specification for Class 5 cement-treated aggregate base course. The field densities achieved equalled or exceeded the specified 97% of standard Proctor value.

A study of cement-treated mixtures of bottom ash and fly ash was undertaken at west Virginia University during the summer of 1972. Compacted samples of the cement-stabilized ash were stored in the moist room and tested in unconfined compression at 8, 30 and 60 days. For comparison, parallel series of samples were prepared using two sources of limestone aggregate commonly used to construct cement-stabilized base courses in north-central West Virginia. The test data indicated that the average strength of the cement-stabilized limestone mixtures was only slightly greater than that of the cement-stabilized ash mixture. In some instances, several of the ash mixtures had greater 30- and 60-day strengths than the limestone mixtures.

3.3 Bottom Ash-Aggregate-Bituminous Mixtures

Successful utilization of bottom ash as a substitute for conventional aggregates in both surface and base course bituminous mixtures was reported by Majidzadeh et al/4/. It was concluded that bottom ash can generally be used in bituminous mixtures for both surface and base course applications as well as in other non-wearing applications. Test results obtained by Majidzadeh et al indicated that most bottom ashes can meet specification limits and design criteria for use in bituminous mixtures. Similar conclusions were obtained by Moulton/3/.

A parking lot on the south side of Ontario Hydro's research laboratory building was constructed with bottom ash mixed with cold asphaltic emulsion as the surface course in the early 1970's. The performance of the pavement surface has been satisfactory from a structural point of view. However, some spots on the pavement surface were discoloured because pyrite was present in the bottom ash.

3.4 Underdrain Applications

Because of the permeable nature of bottom ash material, it is suitable for use as an underdrain filter. A successful

application was reported by Moulton/3/ where bottom ash was utilized to construct an underdrain system for a landslide correction project in West Virginia. Bottom ash has also been used successfully for the construction of an underdrain system in the Booth Quarry in Toronto/9/. In this project, fly ash was used to fill the abandoned quarry and bottom ash was used to construct the underdrain system for the collection of fly ash leachate in a central sump.

3.5 Ontario Hydro's Experience in Using Coal Ash For Highway Construction

Coal ash has been supplied by Ontario Hydro for several highway construction projects. The following is a partial list of such projects.

- E.C. Row/Walker Road overpass in Windsor.
  A mixture of fly ash and bottom ash from J.C. Keith TGS lagoon was used in 1978.
- Highway 403/Eglinton overpass in Toronto.
  Bottom ash from Lakeview TGS was used in 1979.
- Highway 401/Thickson Road access ramps near Whitby.
  Fly ash and bottom ash from Lakeview TGS was used in 1981.
- Highway 402/Front St overpass in Sarnia. Fly ash and bottom ash from Lambton TGS was used in 1981/82.
- Highway 40/Dow overpass in Sarnia.
  Fly ash and bottom ash from Lambton TGS will be used in 1983.

No difficulties were reported in the use of the coal ash as a highway construction material in these projects. These highways have been in operation for several years and all have performed satisfactorily.

4.0 DISCUSSION AND CONCLUSIONS

In this report, the properties of bottom ash obtained by Ontario Hydro and other organizations have been presented. This information will be useful when bottom ash is considered for various applications. In particular, the data will be beneficial to engineers who plan to use bottom ash materials as substitutes for conventional aggregates in highway base courses.

From both published information and Ontario Hydro test data, it can be concluded that the physical and engineering properties of bottom ash materials compare favourably with those of conventional natural aggregates. In terms of particle size

distribution and hydraulic conductivity (k), bottom ash is similar to a granular sandy soil, which has good drainage characteristics. The ash is a "lightweight" material due to the physical and chemical characteristics of the particles. It can be compacted without difficulties and the resulting densities depend on the mixing water content and the compacting effort. The compacted ash exhibits high values of Ø (angle of internal friction) because of the angular and rough surface characteristics of the bottom ash particles. From the limited data available, the breakdown of the ash due to compaction appears to be minimal. From published case records, it can also be concluded that bottom ash materials may indeed be used successfully for many engineering applications, particularly those where lightweight requirements are essential. Naturally, more confidence in using bottom ash for highway base courses can be obtained as additional field experience is accumulated.

Unfortunately, at the present time, some highway agencies are still reluctant to accept the use of bottom ash for highway base and subbase courses. Frequently, when considerations are made in using bottom ash as a substitute for a conventional natural aggregate, some selected properties of the bottom ash are compared with certain standard specifications which were drawn up specifically for granular aggregates. These specifications have been derived from years of engineering experience and are useful for a fast and convenient evaluation of the suitability of conventional natural aggregates for a specific application. For example, in the acceptance of an aggregate as a granular "B" Type I material, which is often used as a highway subbase, the aggregate should meet the physical requirements and the gradation requirements as described by Table XIII/2/.

Since bottom ash is not a natural aggregate, one very fundamental question which one may raise is:

> "To achieve satisfactory performance in a certain engineering application, is it necessary for the bottom ash material to meet the standard specifications established for natural aggregates?"

It is believed that the petrographic number would not be too meaningful for bottom ash materials because they are not natural aggregates. Therefore, the performance of the ash could be poor even though the requirement in the maximum petrographic number is met, or vice versa. With regard to the gradation requirements, it has been shown in this report that in one US project the bottom ash material had to be mixed with fly ash (ie the resulting mix would have excessive fines according to the gradation standards) to improve the stability and the performance of the mix. Therefore, it may be concluded that some

minor deviations of the candidate subbase course material from the gradation requirements would not be significant provided that this fact is recognized and the highway pavement is designed accordingly for this base course material.

It is therefore suggested that the acceptance of bottom ash material for highway base courses should be based on the physical properties of the material itself rather than based on the standard requirements established for conventional natural aggregates.

5.0 RECOMMENDATIONS

From this study, it is recommended that the following future research for the use of bottom ash for highway base courses be pursued:

- A more detailed and extensive full-scale field study be undertaken to investigate the long-term behaviour of bottom ash as a highway base course.
- Specifications be developed on the basis of our knowledge of ash properties and its behaviour in the laboratory and in the field in order that the acceptance of bottom ash for a specific engineering application can be made on a rational and scientific basis.
- The effect of fine particles in bottom ash on frost susceptibility be studied.
- Pavement deflection surveys (Benkleman beam) over MTC highways which have used bottom ash for base courses be conducted.

These data, when acquired, will be used to obtain MTC approval for the use of bottom ash in major road works in Ontario in the future.

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TABLE I

Relative Density (Specific Gravity) of Selected Bottom Ashes

Source of Bottom Ash	Relative Density (Specific Gravity)	Reference
Ontario Hydro	2.66	Clendenning et al/5/
Fort Martin Unit 1	2.35	Seals et al/6/
Fort Martin Unit 2	2.48	Seals et al/6/
Kanawha River	2.28	Seals et al/6/
Mitchell	2.78	Seals et al/6/
21 power generating companies in US	2.08 to 2.49	Majidzadeh et al/4/

TABLE II

Standard Proctor Compaction Results for Several Bottom Ashes/3/*

Source of Ash	Maximum Dry Density (kg/m^3)	Optimum Water Content (%)
Fort Martin Unit 2	1,333	24.8
Kanawha River	1,139	26.2
Mitchell	1,929	14.6

*ASTM D698-66T. Method C, 4-inch mold and minus 3/4-inch material

TABLE III

k Values of Lakeview Bottom Ash

k (cm/s)	Dry Density (kg/m^3)
4.8×10^{-3}	1,451
3.4×10^{-3}	1,442

TABLE IV

k Values of Selected US Bottom Ashes/3/

Source of Ash	Void Ratio	k (cm/s)
Fort Martin Unit 1	0.99	2.8×10^{-2}
Kammer	0.71	6.7×10^{-2}
Kanawha River	1.05	5.0×10^{-3}
Mitchell	0.66	9.4×10^{-2}
Muskingham	0.93	4.0×10^{-2}
Willow Island	0.77	2.5×10^{-2}
Sand*	0.4 - 1.2	1.5×10^{-4} to 2×10^{-1}

* Lambe, T.W. and R.V. Whitman. Soil Mechanics, John Wiley & Sons Inc, New York, p146. 1969

TABLE V

Angle of Internal Friction (ø) of Selected Bottom Ashes in Loose Condition[a] /6/

Source	Average Void Ratio	Angle of Internal Friction, in Degrees
Fort Martin Unit 2	1.41	40.0
Kanawha River	1.68	38.0
Mitchell	1.08	42.5
Ottawa Sand[b]	0.54-0.66	35-29
River Sand[b]	0.61-0.79	41-33
Angular, uniform[c]	-	35-43
Angular, well graded[c]	-	39-45

[a] Direct shear on minus 3/8" material

[b] Lambe, T.W. and R.V. Whitman. Soil Mechanics, John Wiley & Sons Inc, New York

[c] Sowers, George B. and George F. Sowers. Soil Mechanics and Foundations. 3rd Edition. The MacMillan Company

TABLE VI

Variations in Soundness, Los Angeles Abrasion, and Unit Weight of Bottom Ash from Fort Martin/3/

Stockpile	Soundness (Na_2SO_4 % ASTM C-88)	Los Angeles Abrasion % (ASTM C-131)	Unit Weight Pounds Per Cubic Foot
At source.	6	27	81
... "	4	40	74
... "	6	36	83
... "	7	36	82
No 7.....	6	30	83
No 1.....	5	NA	86
No 5.....	8	32	76
No 6.....	4	34	79
No 9.....	4	35	80
No 10.....	5	34	71
No 8.....	5	31	82
At source.	4	30	82
No 3.....	4	30	84
No 4.....	6	32	79

TABLE VII

Relative Density, Water Absorption, L.A. Abrasion and Sulphate Soundness of Representative US Bottom Ash Samples/4/

Sample No	Relative Density (Specific Gravity)	Water Absorption Average	L.A. Abrasion (%)	Sulphate Soundness Average
4	2.48	0.98	30.1	2.44
5	2.62	1.41	34.1	3.02
6	2.44	0.63	32.7	8.62
7	2.15	3.12	49.6	5.95
8	2.24	4.17	50.0	5.90
9	2.26	1.01	45.3	3.21
10	2.14	3.58	44.4	27.92
11	2.71	2.01	37.2	7.89
12	2.49	0.40	43.6	2.97
14	2.59	4.61	33.9	8.09
17	2.73	4.30	37.9	10.10
20	2.20	1.83	-	5.52
21	2.49	1.70	38.3	3.15
22	2.10	2.68	-	2.94
24	2.35	7.52	78.7	4.83
25	2.60	2.02	39.7	1.48
26	2.08	2.46	43.3	5.47
27	2.48	0.83	47.0	2.41
29	2.66	3.87	27.0	6.68
31	2.29	6.69	35.0	7.16

TABLE VIII

Summary of CBR Test Results on Lakeview GS Bottom Ash

Test	Surcharge (g)	Layers/Blows	Wet Density (kg/m^3)	Moisture %	Dry Density (kg/m^3)	CBR %
unsoaked	9071	3/25	1681	26.0	1334	22.0
soaked/8/			1734	27.5	1360	15.3
unsoaked	9071	3/40	1736	26.0	1378	24.1
soaked/8/			1761	27.4	1382	23.8
unsoaked	9071	3/55	1798	26.0	1427	36.4
soaked/8/			1830	27.8	1432	26.5
unsoaked	9071	3/55	1619	29.1	1254	22.5
soaked			1619	34.5	1204	16.5

TABLE IX

Typical Analyses of Lakeview TGS Bottom Ash/5/ Per Cent By Weight - Moisture Free Basis

Silicon (as SiO_2)	45.4
Alumina (Al_2O_3)	25.6
Iron (Fe_2O_3)	13.4
Calcium (CaO)	4.6
Magnesium (MgO)	1.1
Potassium (K_2O)	1.7
Sodium (Na_2O)	1.3
Lead (Pb)	0.01
Zinc (Zn)	0.02
Sulphur (SO_3)	0.42
Loss on Ignition (Basically Carbon)	4.0

TABLE X

Analysis of Bottom Ash Leachates 24H Shake Test At Ash Content of 200 g/kg

Source Sample Designation		Lakeview TGS 'A'	Lakeview TGS 'B'
	pH	7.2	7.0
	Conductivity*	14	11
	C.O.D.	6	2
	Alkalinity as $CaCO_3$ (OH^-)	-	-
	Alkalinity as $CaCO_3$ ($CO_3^=$)	-	-
	Alkalinity as $CaCO_3$ (HCO_3^-)	14.2	16.0
	$SO_4^=$	30	30
	Cl^-	0.3	1.2
	NO_3^-	0.02	0.50
	NO_2^-	<0.02	0.16
Alkalis	Ca	21	18
	K	0.26	0.28
	Mg	1.7	2.1
	Na	0.49	0.74
	Ba	0.03	0.04
	Sr	0.13	0.15
Refractory	Si	1.05	1.70
	Al	0.35	0.66
	Be	<0.00005	<0.00005
	U	0.0001	0.0003
	Th	<0.0001	<0.0001
Transition Metals	Fe	0.25	0.15
	Ti	<0.04	<0.04
	Mn	0.002	<0.002
	V	0.002	0.010
	Cr	0.002	0.003
	Cu	<0.001	<0.001
	Mo	<0.01	<0.01
	Ag	<0.0001	<0.0001
	Co	<0.0001	<0.0001
	Ni	<0.002	<0.002
Volatiles	P	<0.05	<0.05
	Zn	<0.005	<0.005
	B	0.31	0.40
	As	0.020	0.150
	Pb	<0.003	0.007
	Se	<0.001	<0.001
	Cd	0.0002	0.0002
	Hg	<0.0002	<0.0002

*All units in this table are given in mg/L, except for conductivity, which is expressed in mS/m.

TABLE XI

Comparison of West Virginia Department of Highways Requirements for Class 2 Crushed Aggregate Base Course with Typical Properties of Fort Martin Bottom Ash/3/

Sieve Size or Number	Per Cent Finer	
	Class 2 Base Course	Bottom Ash
1-1/2 inches	100	100.0
3/4 inch	80-100	97.0
No 4	35-75	70.3
No 40	10-30	23.0
No 200	0-10	4.5
Los Angeles Abrasion (ASTM C131)	<50	27-40
Sodium Sulphate Soundness (ASTM C88)	<12	4-8

TABLE XII

Comparison of West Virginia Department of Highways Requirements for Class 1 Crushed Aggregate Base Course with Typical Properties of Mixture of 70 Per Cent Mitchell Bottom Ash and 30 Per Cent Blast Furnace Slag/3/

Sieve Size or Number	Per Cent Finer	
	Class 1 Base Course	Bottom Ash Slag Mixture
1-1/2 inches	100	100
3/4 inch	50-90	78.6
No 4	20-50	40.6
No 40	5-20	13.1
No 200	0-7	2.5
Los Angeles abrasion (ASTM C131)	50	37*
Sodium sulphate soundness (ASTM C88)	12	10*

*Maximum for Mitchell bottom ash only

TABLE XIII

Physical and Gradation Requirements of Granular "B" Type I Material

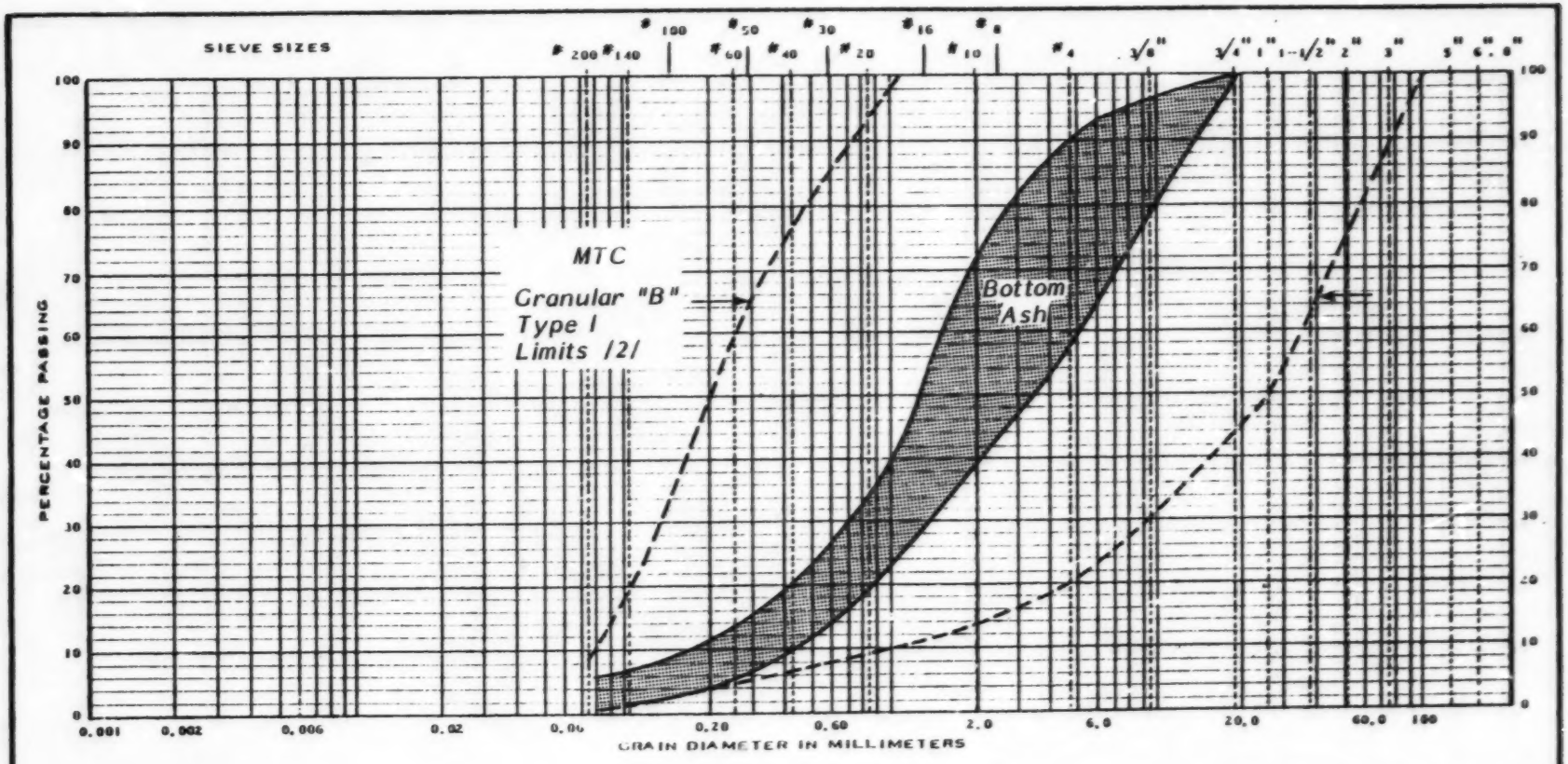
(A) Physical Requirements

Petrographic Number, Maximum	250
Per Cent Crushed, Minimum	-
Plasticity Index (Per Cent)	0

(B) Gradation Requirements (also see Figure 1)

MTC Sieve Designation	% Passing
106 mm	100
26.5 mm	50-100
4.75 mm	20-100
1.18 mm	10-100
300 µm	5- 65
150 µm	2- 30
75 µm	0- 8

MECHANICAL ANALYSIS



CLAY	TO SILT	SAND			GRAVEL		COBBLES
		FINE	MEDIUM	COARSE	FINE	COARSE	

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FIGURE 1

ENVELOPE OF PARTICLE SIZE DISTRIBUTION CURVES
OF LAKEVIEW TGS BOTTOM ASH /1/

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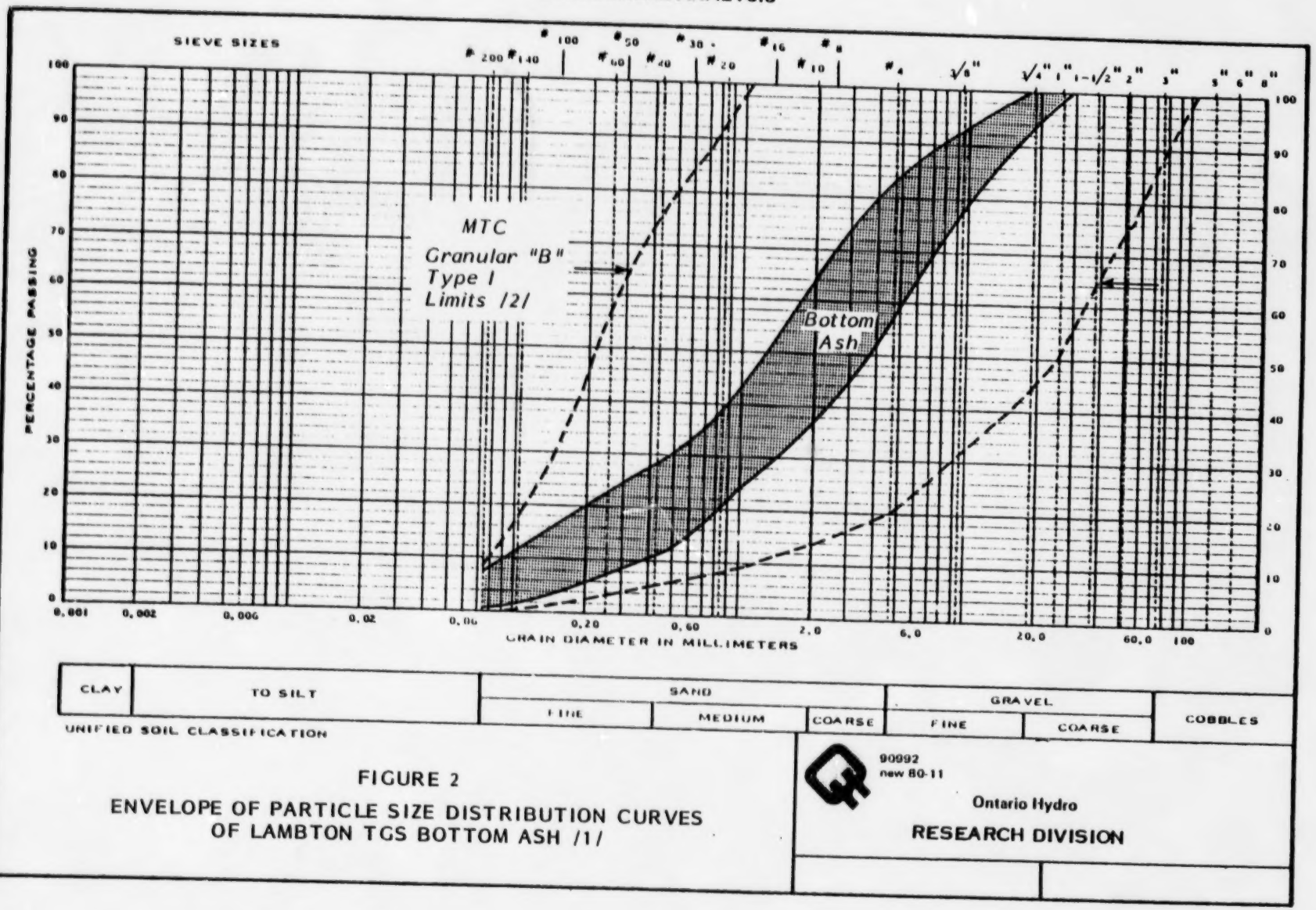

FIGURE 2

ENVELOPE OF PARTICLE SIZE DISTRIBUTION CURVES
OF LAMBTON TGS BOTTOM ASH /1/

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RESEARCH DIVISION

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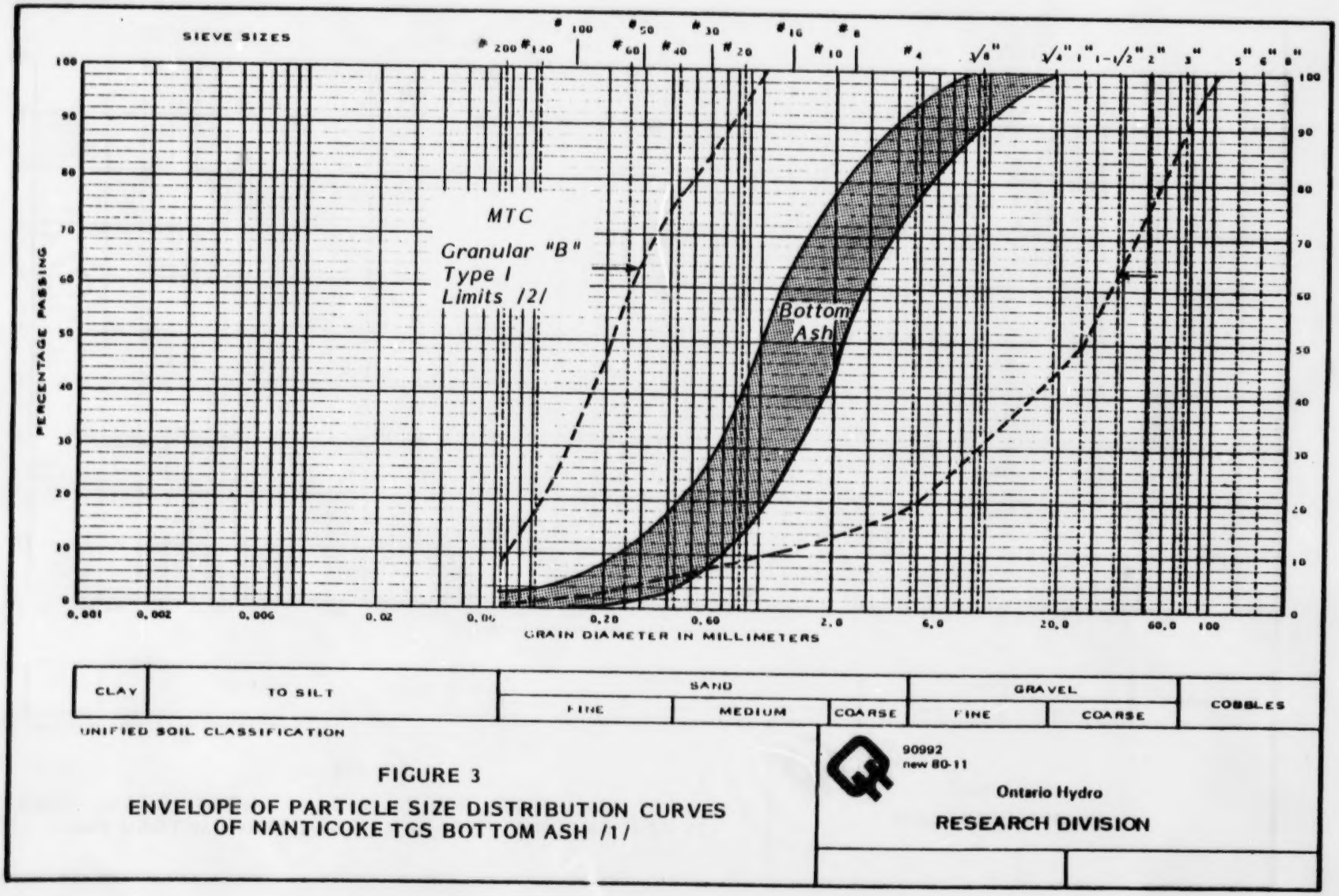

FIGURE 3

ENVELOPE OF PARTICLE SIZE DISTRIBUTION CURVES
OF NANTICOKE TGS BOTTOM ASH /1/

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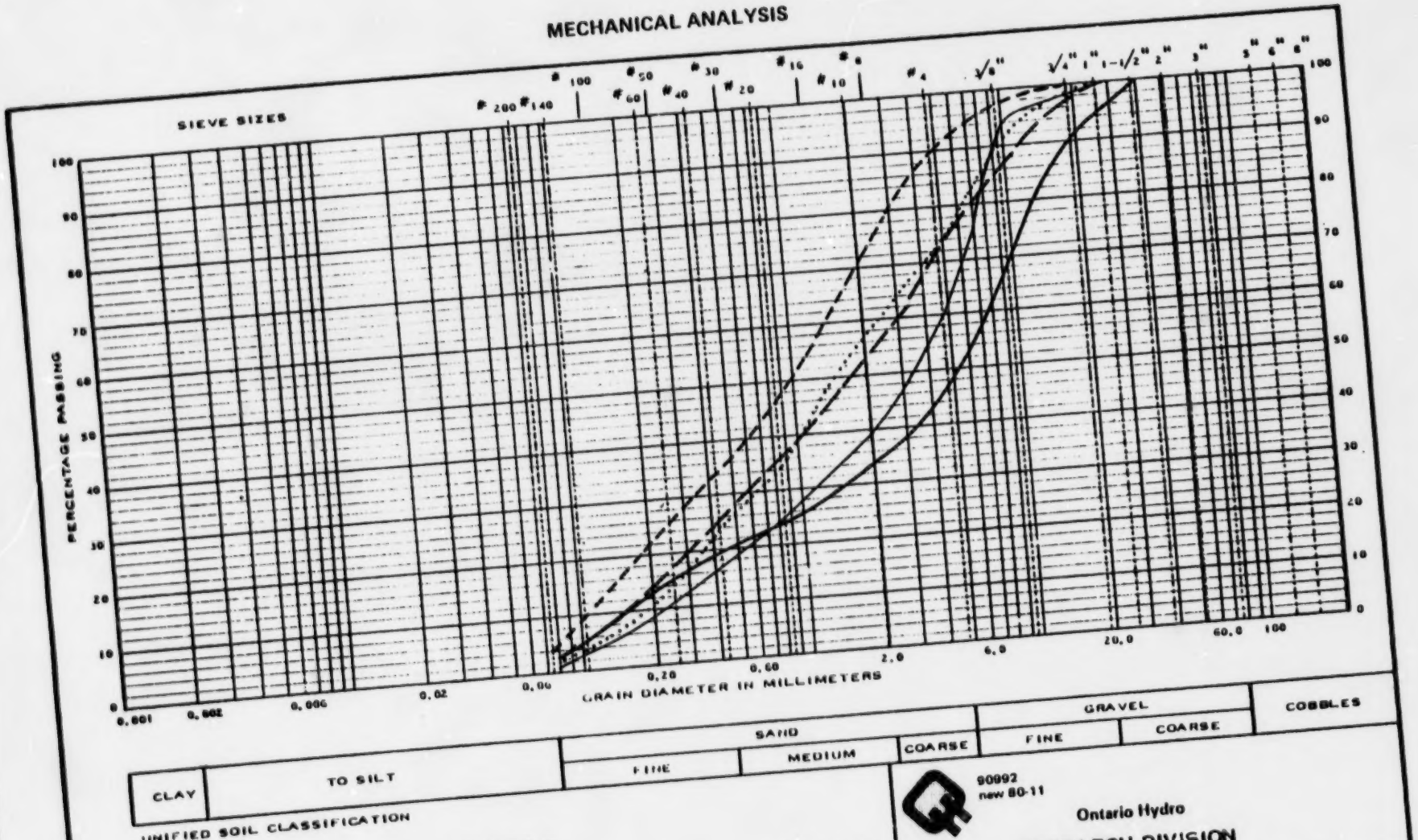

FIGURE 4

GRAIN SIZE DISTRIBUTION CURVES FOR BOTTOM ASH FROM THE FORT MARTIN POWER STATION IN WEST VIRGINIA, USA /3/

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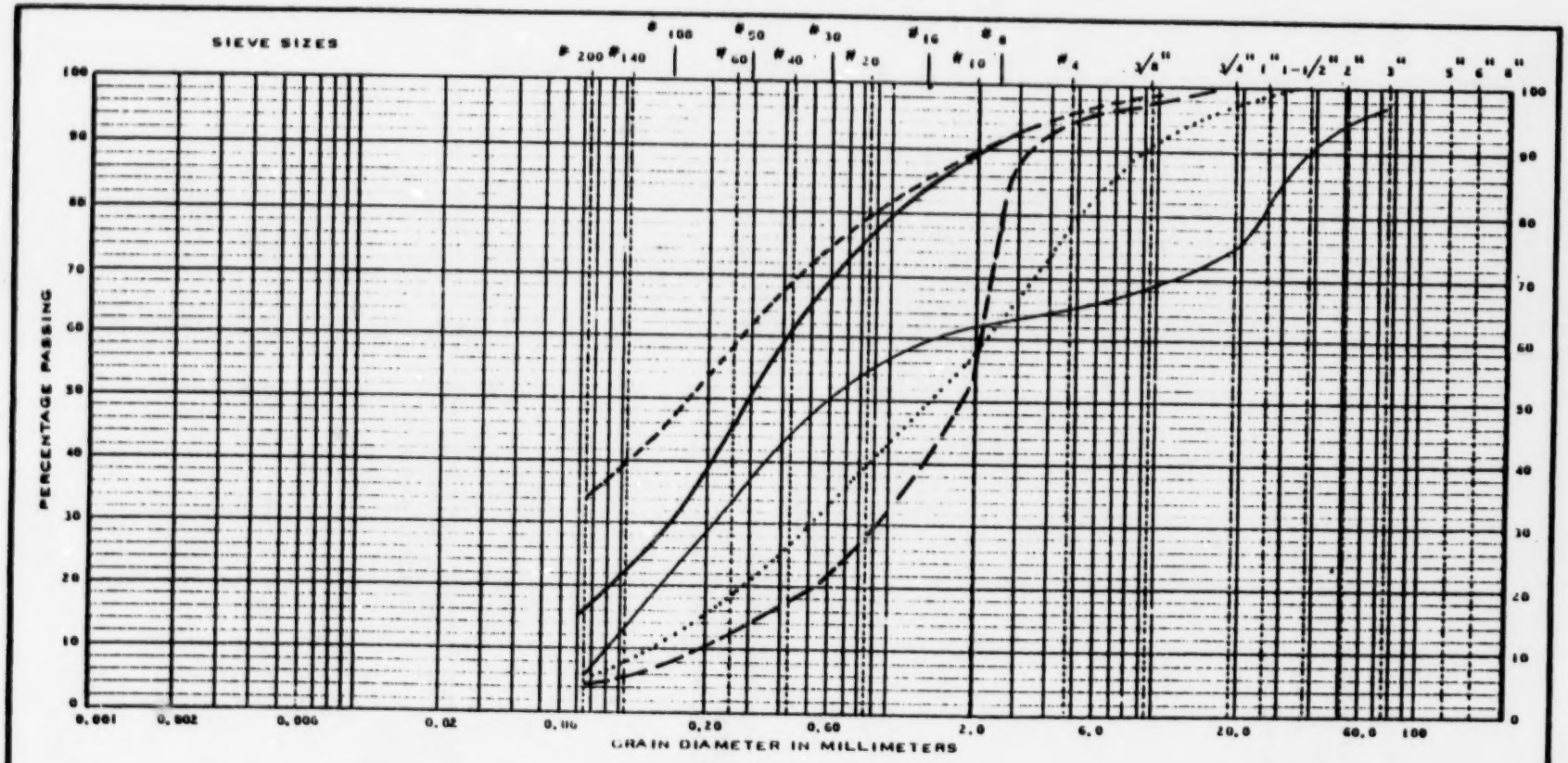
MECHANICAL ANALYSIS



CLAY	TO SILT	SAND			GRAVEL		COBBLES
		FINE	MEDIUM	COARSE	FINE	COARSE	

UNIFIED SOIL CLASSIFICATION

FIGURE 5

GRAIN SIZE DISTRIBUTION CURVES OF REPRESENTATIVE U.S. BOTTOM ASHES /4/

60992
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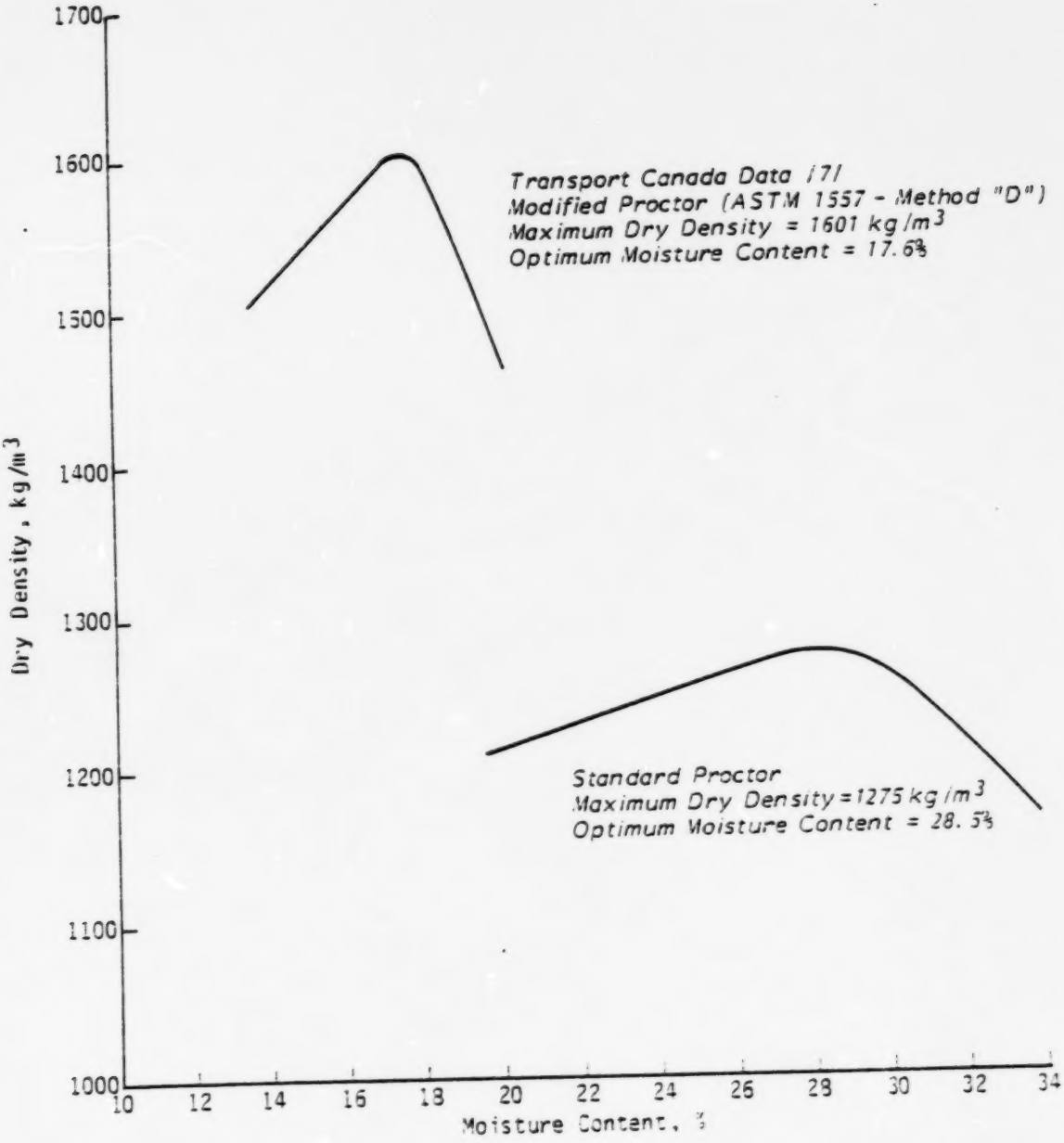
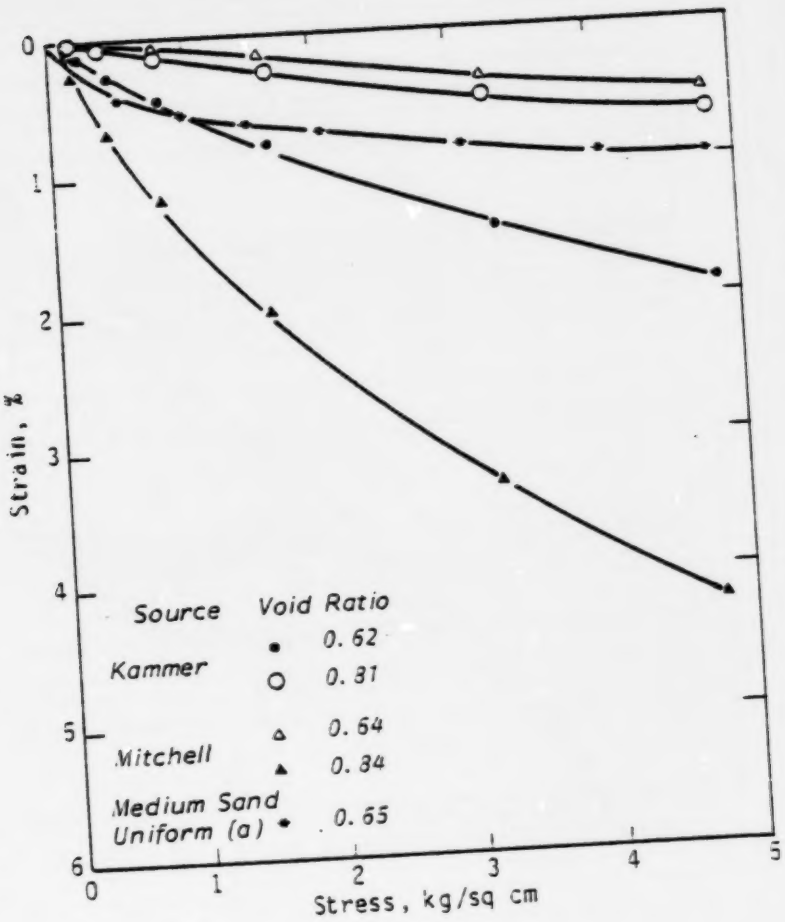


FIGURE 6

MOISTURE-DENSITY RELATIONSHIPS
OF LAKEVIEW BOTTOM ASH SAMPLES

161666 RD



(a) After D.W. Taylor, Fundamentals of Soil Mechanics, John Wiley & Sons, N.Y., 1948

FIGURE 7

ONE-DIMENSIONAL COMPRESSION CURVES FOR SELECTED SAMPLES OF BOTTOM ASH (3)

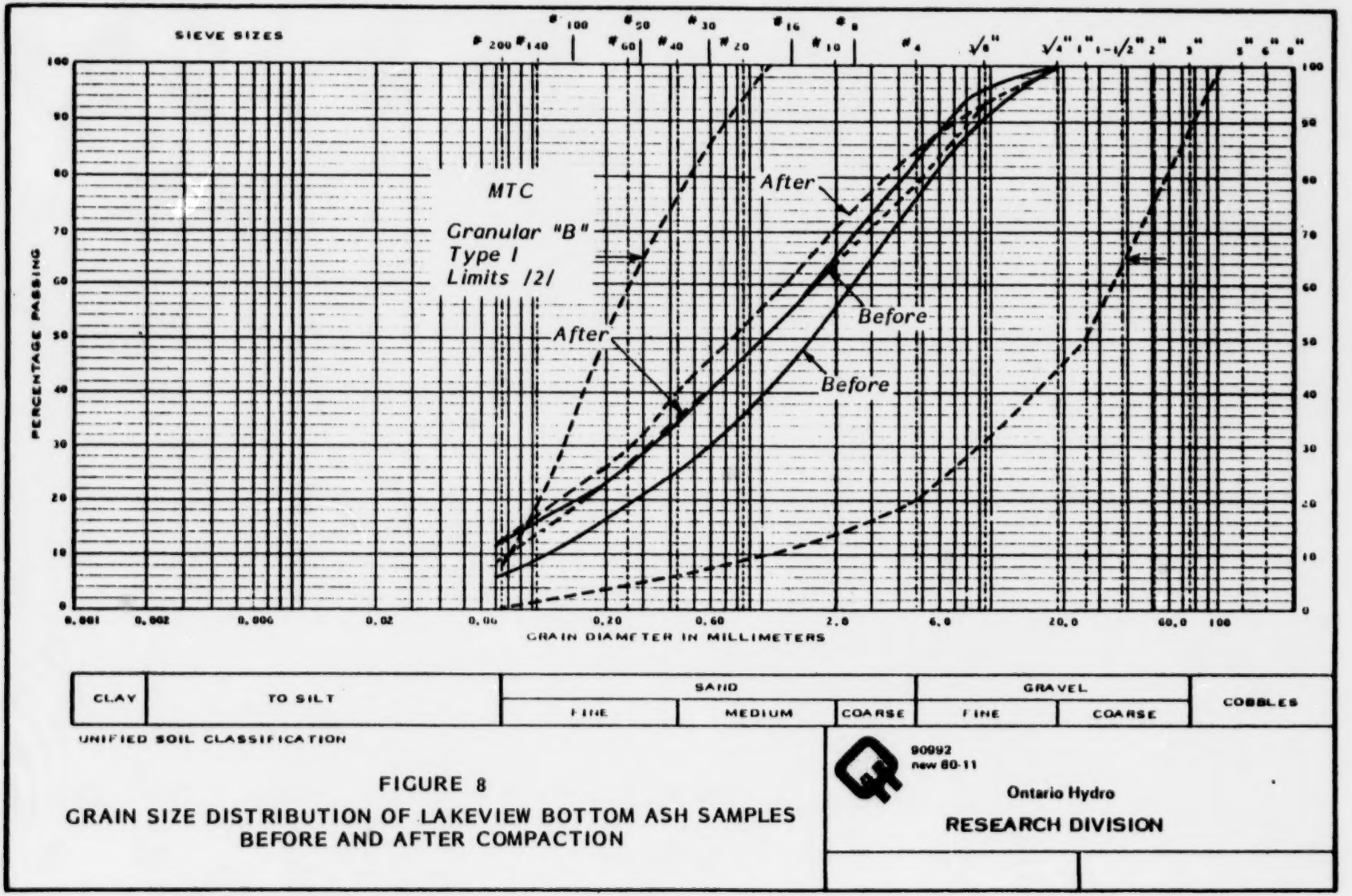


FIGURE 8

GRAIN SIZE DISTRIBUTION OF LAKEVIEW BOTTOM ASH SAMPLES BEFORE AND AFTER COMPACTION

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POOR

QUALITY

ORIGINAL